Chapter 7
Soil Vapor Extraction (In Situ), Bioventing, Biodegradation, Thermally Enhanced Soil Vapor Extraction

7-1. General.

The process of soil vapor extraction (SVE), SVE enhancements, bioventing, and technology applications are included in this section. The second section of the chapter is a hazard analysis, including controls and control points.

7-2. Technology Description.

a. Soil Vapor Extraction Methods.

SVE is the process of extracting soil gas from the vadose zone (the vertical soil zone between the ground surface and the groundwater surface) to convey volatile organic compound vapors (VOCs) to the surface for collection or destruction. The process, illustrated in Figure 7-1, generally consists of wells screened in the unsaturated impacted zone above the water table. The wells are manifolded and connected to a vacuum blower capable of establishing a vacuum on the subsurface soils. The process relies on the combined effects of lowered soil gas pressure (partial vacuum) and soil gas mass flow (soil gas extraction) to enhance volatilization and mass removal of volatile compounds from soil and soil water. The process is dependent on the partitioning of VOCs into the soil gas from the water films and water table (Henry's Law) and/or from a separate phase on the pore space surfaces of the soils (Raoult's Law).

Many VOCs of environmental concern have low water solubility and relatively high vapor pressures, so they are extracted readily by the SVE process. Ancillary equipment is used to protect the pump and to treat the extracted soil gas (typically using vapor phase granular activated carbon or catalytic oxidation). Entry of fresh air can be effected by the installation of infiltration/ induction/ injection wells, or by general infiltration from the surface, or a combination of both.

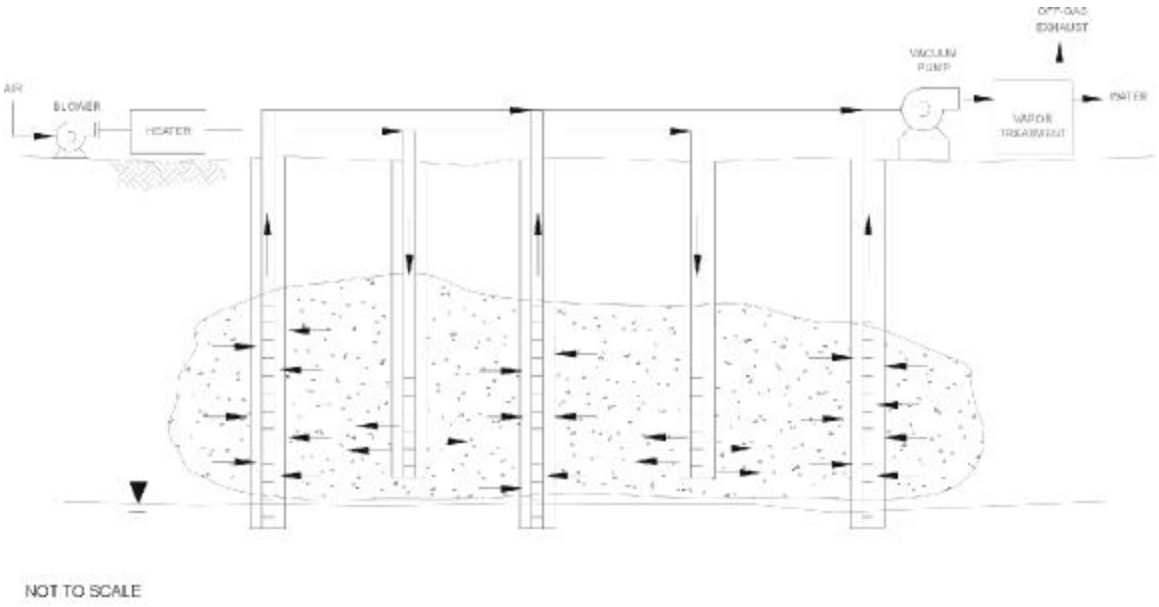

FIGURE 7-1. SVE (IN SITU)/THERMALLY ENHANCED SVE

b. SVE Thermal Enhancements.

SVE systems can be installed with accompanying sparging or air injection processes to enhance the soil gas movement. Occasionally the processes may also be enhanced in rate and extended to some semi-volatile organic compounds (SVOCs) by applying heat to the treatment zone. Heat application is most commonly performed by heating the air prior to its injection or by injecting steam into the subsurface. Since air has a much lower heat capacity than the soil and water it must heat, the rate of heating using air is generally slow. Steam can heat the soil much faster, but excessive heat can kill microorganisms that are degrading the VOC and/or SVOCs present (such as in bioventing). This effect can also alter the soil chemistry and structure, add water (steam condensate) to the soils, enhance mobilization of low solubility and/or low volatility contaminants, and thus (undesirably) mobilize them to the groundwater.

c. Bioventing (In-situ Biodegradation).

In-situ biodegradation, as related to SVE, is termed *bioventing* (Figure 7-2). Bioventing is the process of enhancing in-situ bioremediation of the contaminants in the soils by enhancing the availability of oxygen to the microbes by SVE-type venting processes. The primary parameters that can be altered are: oxygen content of the pore water, nutrient (nitrogen and phosphorus) content of the soil and water, and pH.

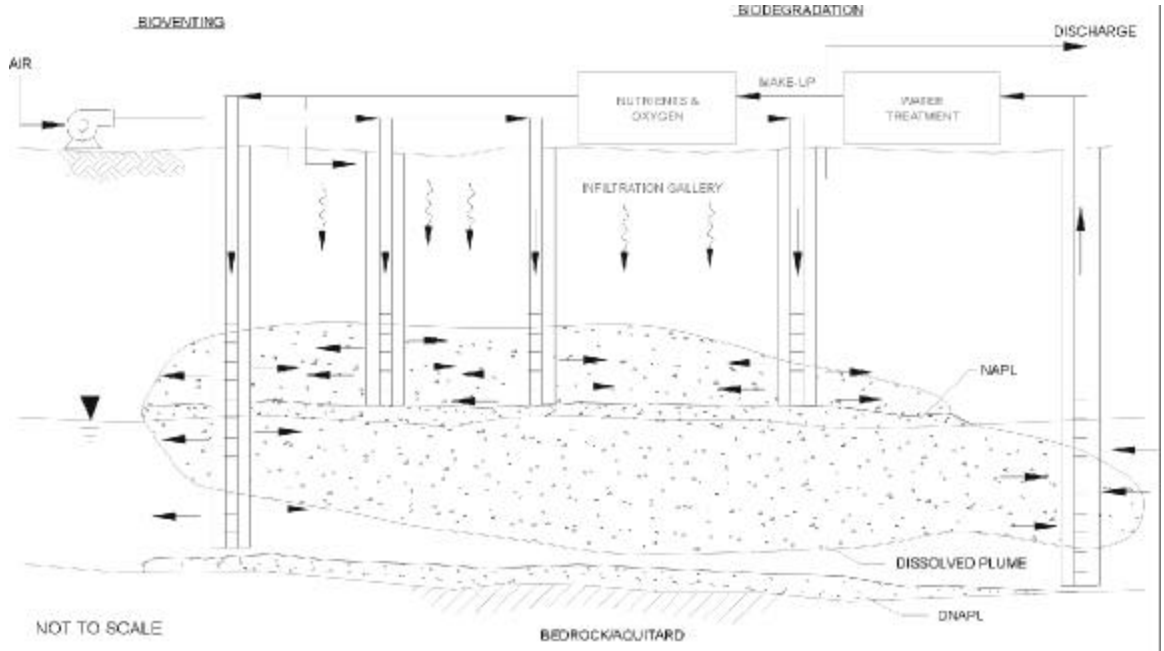

FIGURE 7-2. BIOVENTING/BIODEGRADATION

During bioventing, air drawn or injected into the subsurface provides oxygen to aerobic microorganisms that degrade the VOCs and SVOCs. Since the objective is to provide sufficient oxygen to microbes rather than to use air as a mass remover of VOCs, the rate of air flow is usually lower than with SVE; only the rate needed to sustain biological activity is required. Occasionally, nutrients and water may be added to the subsurface using infiltration galleries to optimize the biodegradation rate or in some cases can be delivered via air into the treatment zone. The degradation process produces carbon dioxide, water, and incompletely digested organic intermediates as the reaction products with the intermediate products subject to further microbial digestion.

d. Bioventing Enhancements.

These venting processes can be enhanced by active injection of air or by induction of air during active air extraction. The latter approach provides for better control of the off gas since active injection of air can cause contaminated soil gas to exit the soil surface, and radially flow through the soil in an uncontrolled manner.

e. Applications.

The processes will remove or biologically alter the chemical structure of many VOCs and SVOCs. Since they are in-situ processes, they minimize exposure to these compounds during the remediation. However, they require longer times to implement than soil removal technologies.

SVE effectively treats fuel component VOCs and chlorinated organic VOCs as well; bioventing effectively treats fuel, VOCs, and some SVOCs. Chlorinated compounds treated with SVE are treated at rates commensurate with their volatilities and solubilities. Chlorinated VOCs may be treated effectively by bioventing, but typically at a slower rate than comparable non-chlorinated organics. This is because the chlorinated compounds are more resistant to microbial metabolism due to the chlorine (trichloroethylene, perchloroethylene, and trichloroethane degrade slowly in bioventing).

7-3. Hazard Analysis.

Principal unique hazards associated with soil vapor extraction (in-situ)/bioventing/biodegradation/thermally enhanced soil vapor extraction, methods for control, and control points are described below.

a. Physical Hazards.

(1) Equipment Hazards (Excavation).
Description: During excavation of trenches during the installation of horizontal piping systems, workers may be seriously injured or killed by heavy equipment such as front-end loaders and scrapers operating in their work areas. This equipment may also generate excessive noise during operation.

Control: Controls for equipment hazards include
- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Wear hearing protection.

CONTROL POINT: Construction, Operations, Maintenance

(2) Utility Contact Hazards.
Description: Fire or explosion hazards may exist if excavation equipment ruptures an underground utility (electrical or gas lines) during installation of the system.

Control: A control for utility hazards includes
- Identify the location of all below- and above-ground utilities by contacting local utilities and public works personnel. When there is any doubt or uncertainty, perform a utility survey, probe with a metal rod, or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful excavation by backhoe may be allowed.

CONTROL POINT: Design, Construction

(3) Fire and Explosion Hazards (Gas Transfer).

Description: During the transfer of flammable gas from the extraction wells or subsurface piping systems to the treatment unit, a fire or explosion hazard may exist. The gas may be ignited by improperly selected or installed equipment.

Control: Controls for fire and explosion hazards during gas transfer include

- Verify that the hazardous area classifications, as defined in NFPA 70-500-1 through 500-10, are indicated on the drawings.
- Use controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.
- Use grounded equipment and/or equipment with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.
- Monitor the atmosphere periodically around the area with a combustible gas monitor. If the concentration of explosive gas reaches 10 percent of the Lower Explosive Level (LEL) or greater, inspect the system for leaks and emission points.
- Control all sources of VOC emissions to prevent the release of flammable gas.
- Install a permanent explosion level meter/alarm if necessary.

CONTROL POINT: Design, Construction

(4) Explosion Hazards (Steam Generator).

Description: Thermally enhanced SVE systems may incorporate the use of steam to heat soils. Pressure caused by plugged steam lines may cause a rupture or an explosion in the system.

Control: Controls for explosion due to steam generators include

- Operate the steam generator within its design parameters and use emergency pressure relief valves.
- Flush steam lines periodically to remove any accumulated scale or deposits.

CONTROL POINT: Design, Operations, Maintenance

(5) Burn and Freezing Hazards.

Description: The surface temperature of uninsulated steam generators and piping systems may reach several hundred degrees and pose a burn hazard to workers. Catalytic oxidation system components can be quite hot, and also pose a burn hazard. Cryogenic systems, associated with O_2 delivery systems, can have very cold surfaces and pose a contact freezing hazard.

Control: Controls for burn and freezing hazards include
- Insulate surfaces properly.
- Include hazard warning signs on the equipment.
- Provide physical covers to prevent contact.

CONTROL POINT: Design, Construction, Operations, Maintenance

(6) Noise Hazards.
Description: High levels of noise may be generated by blowers and compressors and may result in hearing loss.

Control: Controls for noise hazards include
- Use insulated materials, barriers, and properly lubricate and maintain equipment.
- Require personal hearing protection when working in areas of elevated noise levels.

CONTROL POINT: Design, Operations

(7) Unguarded Moving Equipment.
Description: Unprotected blowers and fans may entangle workers' clothing and cause injury.

Control: Controls for moving equipment include
- Guard all moving and rotating equipment.
- Inform workers that all such equipment must be operated with guards in place.
- Train workers in the entanglement hazards.
- Discourage the wearing of loose-fitting clothing.

CONTROL POINT: Design, Operations

(8) Equipment Hazards (Drilling).
Description: During drilling operations, heavy equipment such as augers and pipes are periodically raised overhead and placed into or above the well. Workers may be exposed to swinging equipment during lifting or may be exposed to crushing hazards if the equipment falls. Cables used to raise and lower equipment may also become entangled in loose clothing or other equipment. Direct push drilling methods using hydraulic pressure to advance a soil boring may pose a crushing hazard to hands and/or feet.

Control: Controls for equipment hazards during drilling include
- Post an observer to the side to observe and supervise when raising a drill mast.
- Do not move the drilling rig with the mast raised.

- Secure all loose clothing, use low-profile auger pins, and use long-handled shovels to remove soil cuttings from the borehole.
- Use cable systems with caution and inspect regularly for loose strands or frayed wires that may become entangled in loose clothing.

CONTROL POINT: Design, Maintenance

(9) Electrocution/Fire Hazards (Overhead Lines or Piping Systems).
Description: Electrocution or fire hazards may exist when using hollow-stemmed auger, direct push, or other drilling methods if the drilling mast contacts overhead electric lines or piping systems containing flammable chemicals.

Control: Controls for electrocution include

- Inform all workers as to the location of overhead utilities.
- Drill in an alternative location if possible.
- Keep all lifting equipment (cranes, forklifts, and drilling rigs) at least 10 feet from the power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.E.
- Post a worker to observe and supervise when raising a drill mast.
- Operate the mast at its lowest height; different drill rigs have different mast elevations and may be operated at different heights.

CONTROL POINT: Design, Construction, Maintenance

(10) Electrical Equipment Hazards.
Description: Operation of temporary and permanent electrical equipment, such as lights, generators, and heated SVE system components, may cause electrical hazards.

Control: Controls for electrical equipment include

- Verify that the hazardous area classifications as defined in NFPA 70-500-1 through 500-10 are indicated on the drawings.
- Use all controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazardous areas.
- Use grounded equipment and/or equipment provided with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.

CONTROL POINT: Design, Construction, Operations, Maintenance

(11) Explosion Hazards (Gas Storage).
Description: Improper storage and use of cylinders of compressed gases in some bioventing systems may cause explosive or projectile hazards.

Control: Controls for explosion due to gas storage include

- Store cylinders of compressed gases upright, capped, and secured to prevent movement.
- Avoid extreme temperatures.

CONTROL POINT: Design, Operations

(12) Steam Pressure Washing.
Description: Steam pressure washing of equipment may expose workers to thermal or burn hazards, eye hazards due to flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control: Controls for steam pressure washing include

- Use insulated gloves (e.g., silica fabric gloves).
- Wearing safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(13) Muscle Injuries.
Description: Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control: Controls for muscle injuries include

- Do not require workers to lift heavy loads manually.
- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14.A). Some loads may require two people.
- Use mechanical lifting equipment to lift or to move loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(14) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

(1) Degradation Products.
Description: Biological degradation of certain organic compounds may produce toxic intermediate products. As an example, degradation of trichlorethylene (TCE) can produce dichloroethylene (DCE) and vinyl chloride (VC). Vinyl chloride exists as a gas and may accumulate to higher levels in boreholes or in the system. Workers may be exposed to the degradation products during operation or maintenance of the system.

Control: Controls for degradation products include
- Ventilate the area to minimize exposure.
- Require air-supplied respiratory protection if supported by air monitoring results. (Note: air-purifying respirators are not recommended for vinyl chloride).
- Remediation designers: understand and anticipate the generation and management of general and specific process products such as carbon dioxide, hydrogen sulfide, vinyl chloride (CO_2, H_2S, VC) and design for their management.

CONTROL POINT: Design, Operations, Maintenance

(2) Waste Chemicals and VOC Exposure.
Description: During installation of the wells and system operations and maintenance, workers may be exposed to dermal or inhalation hazards associated with waste chemicals, such as airborne dusts, particulates, and VOC emissions resulting from off gassing or leaks.

Control: Controls for waste chemicals and VOCS include
- Apply water or surfactant amended water solution to the area during installation to help control generation of airborne dusts, particulates, and VOCs.
- Use proper ventilation during installation and operation.
- Use personal protective equipment (PPE) that eliminates exposure hazards (e.g., an air-purifying respirator with organic vapor cartridges).
- Check closed systems, such as SVE, routinely for leaks of the off-gas treatment system with PIDs, air samples, O_2 meters, leak

detection fluids, explosive gas meters, or specific gas tests with chemical-specific detector tubes.
- Repair leaks immediately.
- Make vent stack heights adequate to disperse off gas.
- Designers: anticipate byproducts and products and be certain that technologies selected for treatment (e.g., activated carbon, condensation, catalytic oxidation) of off-gas residuals are both effective and safe.

CONTROL POINT: Design, Construction, Operations, Maintenance

(3) VOC Migration.
Description: Air injection may cause the migration of VOCs to low areas, such as basements, sewers, and other areas. The accumulated, flammable VOCs can cause an explosion or chemical exposure to the occupants.

Control: A control for VOC migration includes
- Test air periodically to ensure safe levels in basements and other areas where VOCs may migrate.

CONTROL POINT: Design, Operations, Maintenance

(4) VOC Exposure (Vents).
Description: Workers may be exposed to VOCs as they are discharged from the blower vent.

Control: Controls for VOC migration include
- Install emission controls, such as activated carbon canisters, on the blower vent discharge.
- Monitor periodically for efficiency.

CONTROL POINT: Design, Operations, Maintenance

(5) Chemical Release.
Description: Fire and/or explosion or chemical release (inhalation/ingestion/asphyxiation) hazards may exist when using hollow-stemmed auger, direct push, or other drilling methods if the drilling bit or bucket ruptures underground utilities, tanks, or piping systems (overhead chemical feed lines) containing hazardous chemicals.

Control: Controls for accidental chemical release include
- Identify location of all below ground utilities by contacting local utilities during design phase.
- Perform a utility survey, probe with a metal rod prior to excavation, or hand excavate to determine the exact location of underground lines prior to drilling.

- Locate overhead hazards and design so that installations using erect equipment are not necessary in that area, if possible.

CONTROL POINT: Design, Construction

c. Radiological Hazards

Radon Exposure.
Description: In some geological settings, workers may be exposed to naturally occurring radon gas. The gas is drawn from the soil in the SVE stream. Radon gas and radon progeny do not present a significant external hazard. While breakdown products of radon (progeny) may present an inhalation/ingestion hazard, quantities of radon progeny normally present would not pose a significant exposure hazard.

Control: Controls for radon exposure include
- Operate emission control technologies properly to limit exposure to acceptable levels.
- Consult a qualified health physicist if excessive levels are encountered or suspected.

CONTROL POINT: Design, Operations, Maintenance

d. Biological Hazards

(1) Biological Contaminants.
Description: At those sites involving medical wastes or sewage sludge, microorganisms in the soil may cause exposure hazards during system installation activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens such as *Coccidioides sp., Histoplasma sp.,* and *Mycobacterium sp.* if contaminated dusts become airborne.

Control: Controls for biological contaminants include
- Reduce the generation of airborne microbe-contaminated dust with the periodic application of water, surfactant amended water, or emission-suppressing foams to the active excavation/drilling areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Erect wind screens and use portable surface covers.
- Use the proper types of PPE: an air-purifying respirator with HEPA (N100, R100, P100) filter/cartridge and rubber gloves.
- Use experienced workers, repeated health and safety meetings, decontamination stations, and other standard procedures.

CONTROL POINT: Construction, Maintenance

(2) Pests.

Description: Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus.

Control: Controls for pests include

- Perform periodic inspections of the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents for exposure control. Workers should check their skin and clothing for ticks periodically.

CONTROL POINT: Construction, Operations, Maintenance